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FLAMMABILITY CHARACTERISTICS OF FIBER-REINFORCED COMPOSITE MATERIALS FOR THE COMPOSITE INFANTRY FIGHTING VEHICLE

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ABSTRACT

The use of composites in Army systems as a means of decreasing weight and enhancing survivability, without reducing personnel safety, has been considered for some time. The U.S. Army Materials Technology Laboratory (MTL) has successfully demonstrated, in an earlier program, that a ground vehicle turret could be fabricated from fiber-reinforced composite material.[1] That technology has now been applied to the fabrication of a composite vehicle hull.

Organic polymers are one of the major constituents of fiber-reinforced composites. As components of military systems, these materials are expected to survive combustion and pyrolysis processes associated with fires. It is thus necessary to develop an understanding of the flammability behavior of composite materials in the early design stages of a military vehicle such as the Composite Infantry Fighting Vehicle (CIFV).

The present study attempts to characterize the flammability behavior of composite materials associated with the CIFV Hull Program in terms of accepted fire resistance parameters.

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INTRODUCTION

Fiber-reinforced composite materials are used extensively because of their physicochemical properties and their high strength/weight ratio (see Table 1). The use of composites in Army systems as a means of decreasing weight and enhancing survivability, without reducing personnel safety, has been considered for some time. The U.S. Army Materials Technology Laboratory (MTL) has successfully demonstrated, in an earlier program, that a ground vehicle turret could be fabricated from fiber-reinforced composite material.[1] That technology has now been applied to the fabrication of a composite vehicle hull.

Table 1. CANDIDATE COMPOSITE MATERIALS

Sample No.	Fiber/Resin	Ratio	Comments
MTL-1	S2/Polyester	70/30	E-701 Baseline
MTL-2	S2/Polyester*	70/30	Owens-Corning
MTL-3	S2/Polyester*	70/30	American-Cyanamide
MTL-4	Kevlar/Phenolic-PVB†	84/16	Russell Corporation
MTL-5	S2/Phenolic	80/20	Owens-Corning

*Resin formulation is proprietary.
†Resin is 50/50 Phenolic-PVB.

Organic polymers are one of the major constituents of fiber-reinforced composites. As components of military systems, these materials are expected to survive combustion and pyrolysis processes associated with fires. It is, therefore, necessary to develop an understanding of the flammability behavior of composite materials in the early design stages of a military vehicle; assessments can then be made of potential fire hazards and the type(s) of protection that may be required. This report describes the results of a study on fiber-reinforced composite materials which was undertaken to quantify data and gain an understanding of the processes associated with combustion, pyrolysis, fire propagation, and fire extinguishment.

In the study, laboratory scale techniques were used to quantify the following: thermal response, by thermal analysis techniques; ease of ignition, by limiting oxygen index and its dependence on temperature; smoke generation, by smoke density measurement; and combustion effluent composition, by pyrolysis/gas chromatography/mass spectrometry. Simultaneously, and independent evaluation of the same composite materials was initiated by Factory Mutual Research Corporation (FMRC) of Norwood, MA, under Contract DAALO4-87-C-0078 to MTL, to further define the flammability characteris ther reinforced composite materials by laboratory methods unique to that organization.

At FMRC, the composite material test specimens were evaluated in terms of critical heat flux (the minimum heat flux at or below which there is no ignition), thermal response of the material expressed in terms of ignition temperature, thermal conductivity, density, and specific

1 SULLIVAN, F R. *Reinforced Plastic Turret for M2/M3* FMC Corporation Final Report, Contract DAAG46-83-C-0041. U S Army Materials Technology Laboratory, MTL TR 87-39, August 1987

heat, heat of gasification, chemical heat of combustion and its convective and radiative components, fire propagation rate, yields of various chemical compounds (e.g., CO, CO_2, total gaseous hydrocarbon, soot particulates), and optical properties of smoke, flame radiative heat flux (expected in large-scale fires), and flame extinction using Halon 1301. The results of that evaluation have been published as a separate report by FMRC.[2]

EXPERIMENTAL

Thermal Analysis

A thermogravimetric analysis (TGA) system, consisting of a DuPont Instruments 9900, computer controlled, thermal analyzer and 951 TGA module, was employed to determine sample mass loss as a function of temperature in a flowing gas atmosphere (air or argon), as appropriate, at a preset flow rate of 100 cc/min. Experiments were conducted in both the dynamic and isothermal mode. The resultant data indicates the thermal stability of the material being examined. In general, materials that are thermally stable are less flammable than those that are thermally labile, since the concentration of low molecular weight, combustible, fragments is decreased at any given temperature up to the point where major decomposition of the material occurs.

The isothermal decomposition experiment is a variation of the dynamic TGA measurement described above. The same apparatus is employed with the same atmosphere existing within the apparatus; however, in this experiment the thermal level is fixed and the change in sample mass is recorded as a function of time. The experimental results indicate the ability of the test specimen to withstand a sudden exposure to elevated temperatures at preset levels.

Limiting (Critical) Oxygen Index

As a measure of susceptibility to ignition, values of limiting oxygen index were determined for the composite material specimens employing a Stanton-Redcroft HFTA Oxygen Index apparatus. Specimens were evaluated according to the provisions of ASTM-D-2863-87. The results indicate the minimum concentration of oxygen that is required by the material being examined to sustain equilibrium combustion. Materials with low oxygen indicies (21%, or less) can be expected to burn readily in normal atmospheric conditions. Materials with moderate oxygen indicies (21% to approximately 27%) can be expected to ignite with increasing difficulty and to self-extinguish in normal atmosphere.

Temperature Dependence of Oxygen Index

To evaluate the change in oxygen index as a function of temperature for each material, a series of experiments was conducted with a Stanton-Redcroft HFTA apparatus. With this system it is possible to repeat the oxygen index determination with the test specimen at temperatures between ambient and $300^{\circ}C$. The results indicate the change in oxygen requirements to sustain combustion of the sample as the temperature to which the material is exposed is allowed to increase. By determining the oxygen index at several temperature levels it is possible to plot a profile of the change in ignition behavior of the material.

2. TEWARSON, A. *Flammability Characteristics of Fiber-Reinforced Composite Materials* Factory Mutual Research Corporation Technical Report J0P2N1 RC079(A) Work performed under U.S. Army Materials Technology Laboratory, MTL Contract DAAL04-87-C-0075 September 1990

Smoke Density Measurements

To determine the smoke density values for each material, measurement of smoke generation was conducted in an NBS Smoke Chamber. Specimens were evaluated in smoldering and flaming mode according to the provisions of ASTM-E-662. In the smoldering mode, the test specimen is subjected to the thermal energy of an electric heating element adjusted so that the sample surface receives 2.5 watt/sq cm, at which level the surface temperature is approximately $350^{\circ}C$. In the flaming mode, the smoldering conditions are augmented with a six jet propane burner oriented to impinge flame on the lower portion of the test specimen. The smoke density value is determined by the decrease in light transmission as measured by a photometer. Values of optical density are quoted, as appropriate, with larger values indicating more smoke produced by the sample being tested.

Pyrolysis/Gas Chromatography/Mass Spectrometry

To evaluate combustion effluent, composition samples of approximately 2 mg were pyrolyzed in flowing helium using a Chemical Data Systems (CDS) Platinum Coil Pyrolysis Probe controlled by CDS Model 122 Pyroprobe in normal mode. Effluent components were separated on 12 meter fused capillary column with a cross-linked poly(dimethylsiloxane) stationary phase. The gas chromatography (GC) column was temperature programmed from $-50^{\circ}C$ to $300^{\circ}C$. Component identification was accomplished with a Hewlett-Packard Model 5995C low resolution quadrupole GC/MS system. Data aquisition and reduction was accomplished using a Hewlett-Packard Model 1000 E-Series Computer using Revision E RTE-6/VM Software.

RESULTS

Thermal Analysis

Data representative of the dynamic thermogravimetric analysis experiments are presented in Table 2. A graphic plot of mass loss as a function of temperature is shown in Figure 1. Presentation in this format was chosen to permit direct comparison of the experimental results.

Table 2. THERMOGRAVIMETRIC ANALYSIS RESULTS

Sample No.	Temp (°C)	Event/Condition	WT (%)
MTL-1	Amb-200	Mass Loss	2.0
	200-500	Mass Loss	30.0
	500-800	Mass Loss	4.0
	900	Steady State	64.0
MTL-2	Amb-200	Mass Loss	0.4
	200-500	Mass Loss	33.0
	500-800	Mass Loss	1.5
	900	Steady State	65.0
MTL-3	Amb-200	Mass Loss	0.5
	200-500	Mass Loss	24.0
	500-800	Mass Loss	4.0
	900	Steady State	72.0
MTL-4	Amb-200	Mass Loss	0.7
	200-500	Mass Loss	34.0
	500-800	Mass Loss	65.0
	900	Steady State	0.3
MTL-5	Amb-300	Mass Loss	0.6
	300-650	Mass Loss	17.0
	650-850	Mass Loss	0.0
	850	Steady State	83.0

1 - MTL #1, S2/Polyester
2 - MTL #2, S2/Polyester
3 - MTL #3, S2/Polyester
4 - MTL #4, Kevlar/Phenolic-PVB
5 - MTL #5, S2/Phenolic
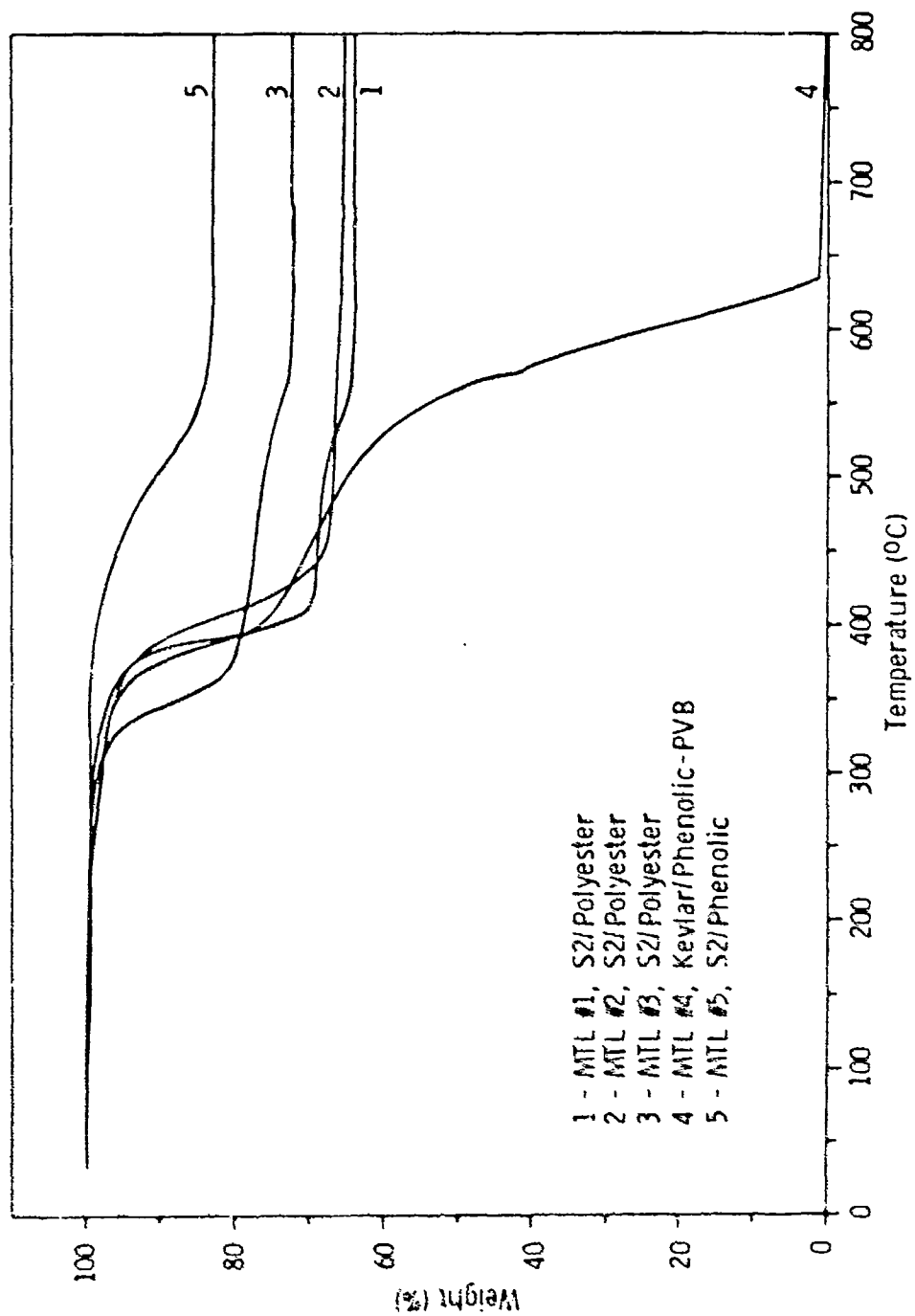
Figure 1 Thermogravimetric analysis in air.

Data representative of the results of isothermal decomposition experiments are presented in Table 3. A graph plot of mass loss as a function of time for one of the composites, MTL-3, is shown in Figure 2.

Table 3. ISOTHERMAL DECOMPOSITION

| Sample No. | Percent Mass Loss During Five Minute Exposure | | | |
	300°C	400°C	500°C	% Residue (500°C)
MTL-1	0.73	29.79	32.87	60.09
MTL-2	2.04	24.13	29.10	70.49
MTL-3	3.07	25.13	30.02	67.39
MTL-4	3.09	28.87	54.01	10.38
MTL-5	0.04	3.07	9.11	82.14

Oxygen Index/Temperature Dependence of Oxygen Index

The results of experimental determination of the oxygen index and the temperature dependence of oxygen index are presented in Table 4. Graphic plots are shown in Figure 3.

Table 4. OXYGEN INDEX/TEMPERATURE DEPENDENCE OF OXYGEN INDEX

Temp. (°C)	MTL-1	MTL-2	MTL-3	MTL-4	MTL-5
25	23	28	52	28	53
100	23	28	95	30	98
200	5.4	13	77	29	94
300	< 1	< 1	41	26	80

The parameter commonly referred to as the limiting or critical oxygen index is represented by the initial value, at 25°C, for each material.
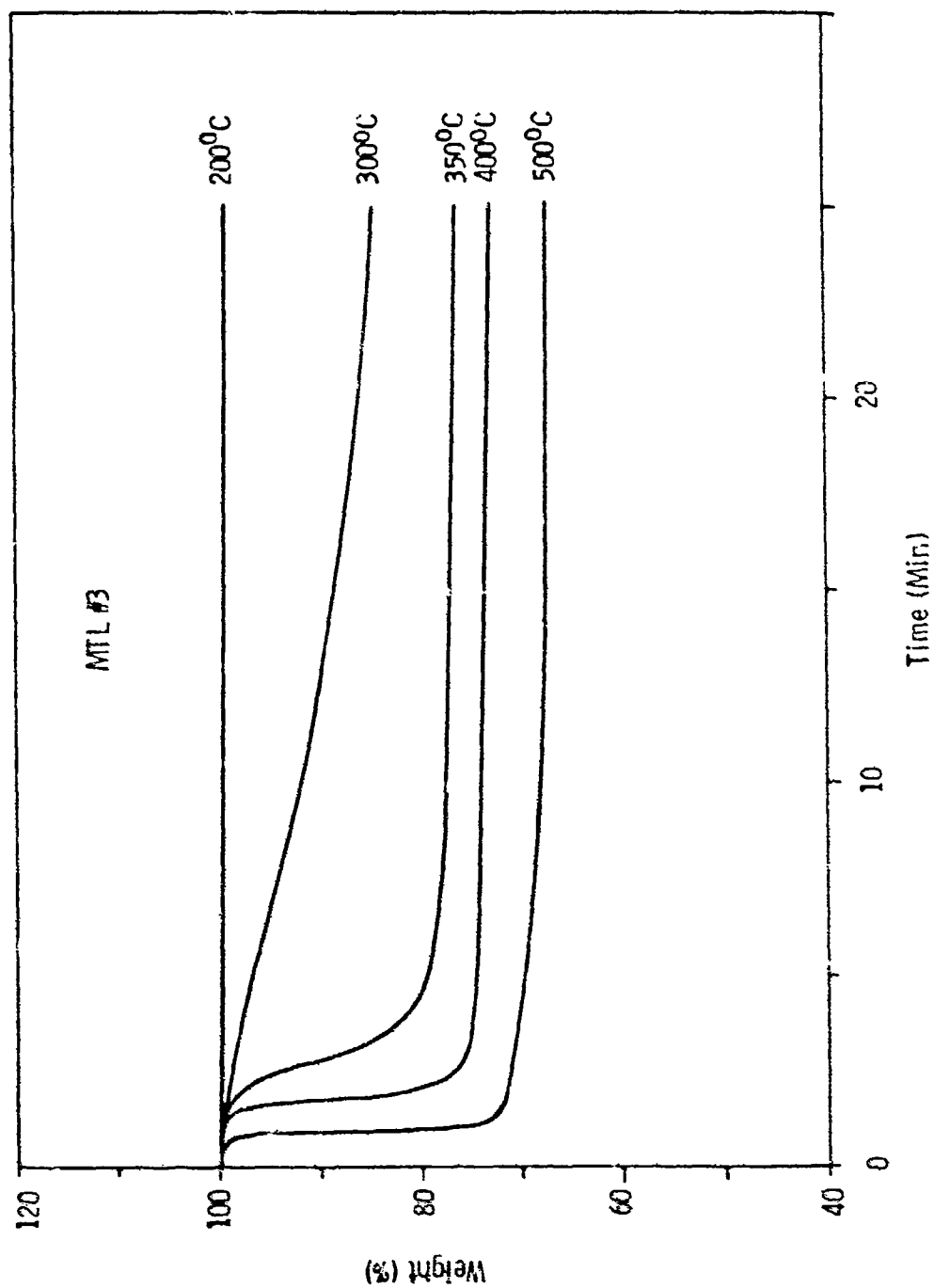
Figure 2   Isothermal decomposition in air.
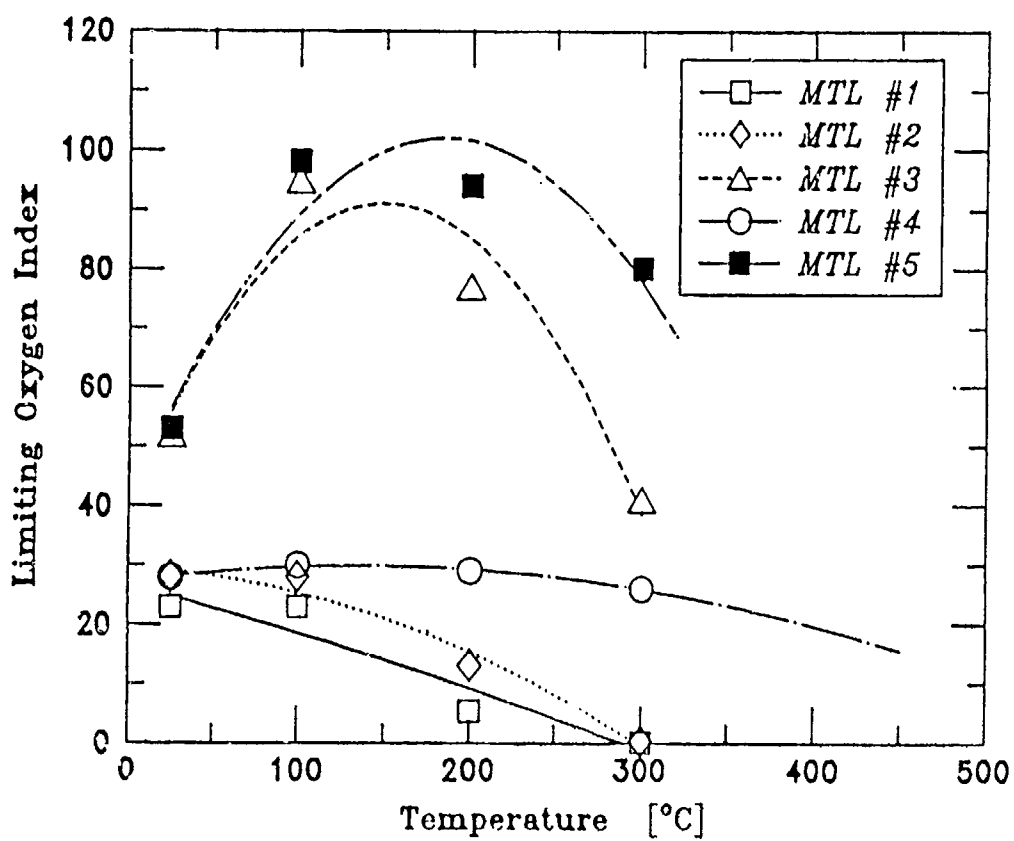
Figure 3. Limiting oxygen index as a function of environmental temperature in the oxygen index apparatus for composite materials.

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Smoke Density Measurement

Table 5 contains the results of experimental smoke density determinations performed on samples of MTL-1 through MTL-5. A representative plot of smoke density, in terms of decreasing light transmission, as a function of time is shown in Figure 4.

Table 5. SMOKE DENSITY VALUES, MTL-1 THROUGH MTL-5

MTL No.	Time to Ds = 16	Time To Ds = 264	Dm (corr)	SD/G
1s	6 min	20 min	238	80
1f	2 min	4.5 min	368	45
2s	6 min	—	219	88
2f	2 min	11 min	372	62
3s	4 min	13 min	241	38
3f	2 min	3.5 min	406	50
4s	11 min	—	61	20
··	< 1 min	—	226	35
5s	—	--	1	2
5f	12 min*	—	14	20

*Only one of the several specimens tested reached Ds = 16 within the 20 minute test limit.

Notes:

1. Test mode: s = smoldering   f = flaming

2. Time to Ds = 16 is the time required to reach 75% light transmission. Time to Ds = 264 is the time required to reach 1% light transmission.

3. Dm (corr) = Dm-Dc where Dm is maximum optical density and Dc is the clear beam reading.

4. Test specimen surface temperature in smoldering mode is 350^0C (622^0F).

5. SD/G = smoke density/gram = Dm (corr)/unit mass of sample.
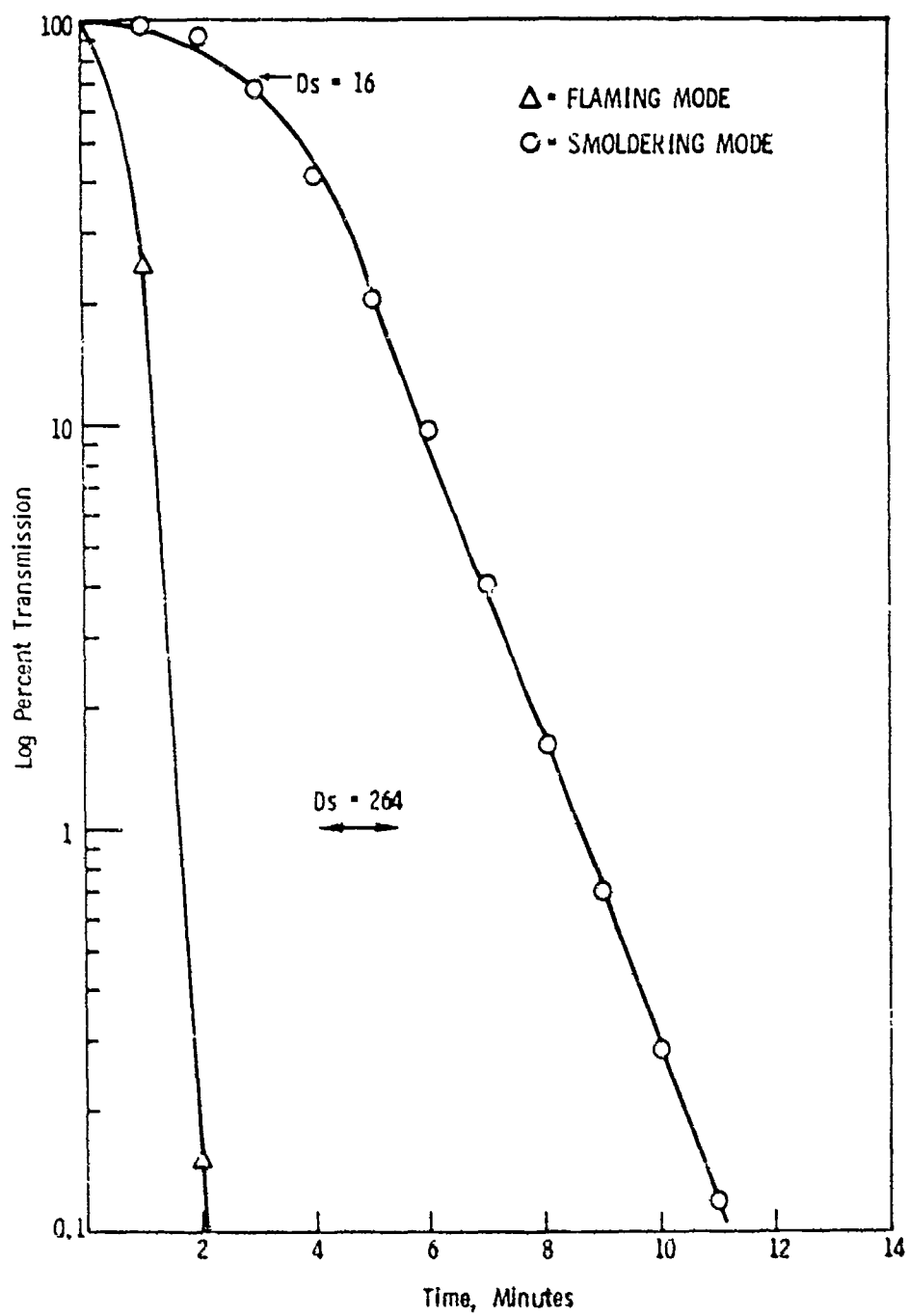
Figure 4   Smoke Density - loss of light transmission versus time (min).

100

Ds = 16

△ = FLAMING MODE
O = SMOLDERING MODE

Log Percent Transmission

10

1

Ds = 264

0.1

2   4   6   8   10   12   14

Time, Minutes

10

Pyrolysis/Gas Chromatography/Mass Spectrometry

The results of pyrolysis/gas chromatography/mass spectrometry experiments performed as a means of assessment of combustion effluent composition are shown in Tables 6 through 10 and Figures 5 through 9. Pyrolysis was performed at 900°C, in helium, because an oxidative atmosphere is not compatible with the analytical system in the present configuration. The total number of separated/identified constituents varied from 19 for MTL-5 to 39 for MTL-2. Many compounds appeared to be constituents of more than one resin formulation, which is not unexpected

Table 6. PYROLYSIS/GAS CHROMATOGRAPHY/MASS SPECTROMETRY
OF MTL-1, E-701 BASELINE; 900°C IN HELIUM

Peak No.	Identification
1	Carbon Dioxide
2	Propene
3	Propyne or 1,2-Propadiene
4	Ethylene oxide
5	Butene
6	1,3-Butadiene
7	2-Propenal
8	Methoxyethene
9	1,3-Pentadiene
10	Cyclopentadiene
11	Propenol
12	Benzene
13	Toluene
14	2,5 Furandione
15	Ethylbenzene
16	Styrene
17	Isopropylbenzene
18	Cyclopropylbenzene
19	n-Propylbenzene
20	1-Propenylbenzene
21	Methylpropylbenzene
22	C9.H10

Table 6 (cont'd). PYROLYSIS/GAS CHROMATOGRAPHY/MASS SPECTROMETRY OF
MTL-1, E-701 BASELINE; 900°C IN HELIUM

Peak No.	Identification
23	1-Propynylbenzene
24	3-Butenyibenzene
25	1-Phenyl-1-propanone
26	Naphthalene or Azulene
27	2-Propenyl ester of benzoic acid
28	C11.H1ʊ
29	2-Ethenylnaphthalene
30	Dimethylphthalate
31	Methylbiphenyl
32	1,1'-(1,2-Ethanediyl)bis-benzene
33	1,1'-(1,3-Propanediyl)bis-benzene
34	9,10-Dihydroanthracene
35	Diisopropenylphthalate
36	2-Phenylnaphthalene

Table 7. PYROLYSIS/GAS CHROMATOGRAPHY/MASS SPECTROMETRY OF MTL-2, OWENS-CORNING; 900°C IN HELIUM

Peak No.	Identification
1	Carbon Monoxide and Carbon Dioxide
2	Formaldehyde
3	Propene
4	1,2-Propadiene
5	1-Propyne
6	Ethylene oxide
7	Butene
8	1,3-Butadiene
9	Propenal
10	1,3-Pentadiene and Propanal and Acetone
11	Ethylcyclopropane
12	1,3-Cyclopentadiene
13	2-Propen-1-ol
14	Benzene
15	Toluene
16	2,5-Furandione
17	Ethylbenzene
18	Styrene
19	Isopropylbenzene
20	2-Methylstyrene
21	n-Propylbenzene
22	1-Propenylbenzene
23	C_9H_{10}
24	1,2-Propadienylbenzene
25	3-Butenylbenzene
26	Methylenepropylbenzene
27	$C_{10}H_{10}$ isomers
28	Naphthalene or Azulene
29	2-Propenyl ester of benzoic acid

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Table 7 (cont'd). PYROLYSIS/GAS CHROMATOGRAPHY/MASS SPECTROMETRY OF
MTL-2, OWENS-CORNING; 900°C IN HELIUM

Peak No.	Identification
30	Phthalic anhydride
31	Methylnaphthalene
32	Biphenyl
33	1,1'-(1,2-ethanediyl)bis-benzene
34	2-Propenylester-3-phenyl-2-propenoic acid
35	9,10-Dihydroanthracene
36	Diallylphthalate
37	Diisopropenylphthalate isomers
38	2-Phenylnaphthalene
39	Terphenyl

Table 8. PYROLYSIS/GAS CHROMATOGRAPHY/MASS SPECTROMETRY OF MTL-3, AMERICAN-CYANAMIDE; 900°C IN HELIUM

Peak No.	Idenification
1	Carbon Monoxide and Carbon Dioxide
2	Propene
3	HCl
4	Chloromethane
5	Chloroethene
6	Butene
7	1,3-Butadiene
8	Methoxyethene
9	Chloropropene isomers (4)
10	Cyclopentadiene
11	Benzene
12	Toluene
13	2,5-Furandione
14	Chlorobenzene
15	Ethylbenzene
16	Dimethylbenzene
17	Styrene
18	Phenol and Benzofuran
19	Methylsytrene, Methylethylbenzene, 4-Nonen-2-yne and Dichlorobenzene
20	4-Methyl-1-ethynylbenzene
21	Naphthalene or Azulene
22	Phthalic anhydride
23	1,2,3,4,5,5-Hexachloro-1,3-cyclopentadiene
24	Tetrachlorobenzene
25	Biphenyl
26	2,4-Dichloro-1-(2-Chloroethenyl) Benzene isomers
27	1,2,4-Trichloro-5-(chloromethyl)benzene

Table 8 (cont'd). PYROLYSIS/GAS CHROMATOGRAPHY/MASS SPECTROMETRY OF
MTL-3, AMERICAN CYANAMIDE; 900°C IN HELIUM

Peak No.	Identification
28	9H-Fluorene
29	1-Chloro-3-(trichloroethenyl)benzene
30	Phenyl ester of benzoic acid
31	Di-(2-propenyl)phthalate
32	Phenanthrene or 9-Methylene-9H-fluorene
33	Chlorendic acid
34	Butylbenzylphthalate
35	Triphenylene

Table 9. PYROLYSIS/GAS CHROMATOGRAPHY/MASS SPECTROMETRY OF
MTL-4, RUSSELL CORPORATION; 900°C IN HELIUM

Peak No.	Identification
1	Methane and Carbon Dioxide
2	Propene
3	Hydrogen cyanide
4	Ethylene oxide
5	Butene
6	C_4H_6
7	Butenes
8	Propenal
9	Acetone
10	Ethylcyclopropane
11	1,3-Pentadiene
12	Cyclopentadiene
13	Cyclopentene
14	Butanal

Table 9 (cont'd). PYROLYSIS/GAS CHROMATOGRAPHY/MASS SPECTROMETRY OF MTL-4, RUSSELL CORPORATION; 900°C IN HELIUM

Peak No.	Identification
15	Methylpropenone
16	Benzene
17	Pentenone isomers
18	Toluene
19	Dimethylbenzene
20	Styrene
21	Isocyanobenzene
22	Phenol
23	Methylphenols
24-26	Dimethylphenol isomers
27	Trimethylphenol
28	Biphenyl
29	Acridine
30	N-(phenyl)benzamide
31	2-Phenyl-1H-isoindole-1,3-(2H)-dione
32	Chlorinated unknown
33	2-[1,1'-Biphenyl]-4-yl-1H-isoinolde-1,3-(2H)-dione

Table 10. PYROLYSIS/GAS CHROMATOGRAPHY/MASS SPECTROMETRY OF MTL-5, OWENS-CORNING; 900°C IN HELIUM.

Peak No.	Identification
1	Methane and Carbon Dioxide
2	Propene
3	Acetone
4	2-Propanol
5	1,3-Cyclopentadiene
6	Benzene
7	Toluene
8	Dimethylbenzene
9	Styrene
10	Trimethylbenzene
11	Phenol
12	Methylphenol
13	Methylphenol
14	Dimethylphenol
15	Dimethylphenol
16	Trimethylphenol
17	4-Hydroxyphthalate or 9H-Xanthene
18	2-Methylanthracene
19	Methylene bis phenol
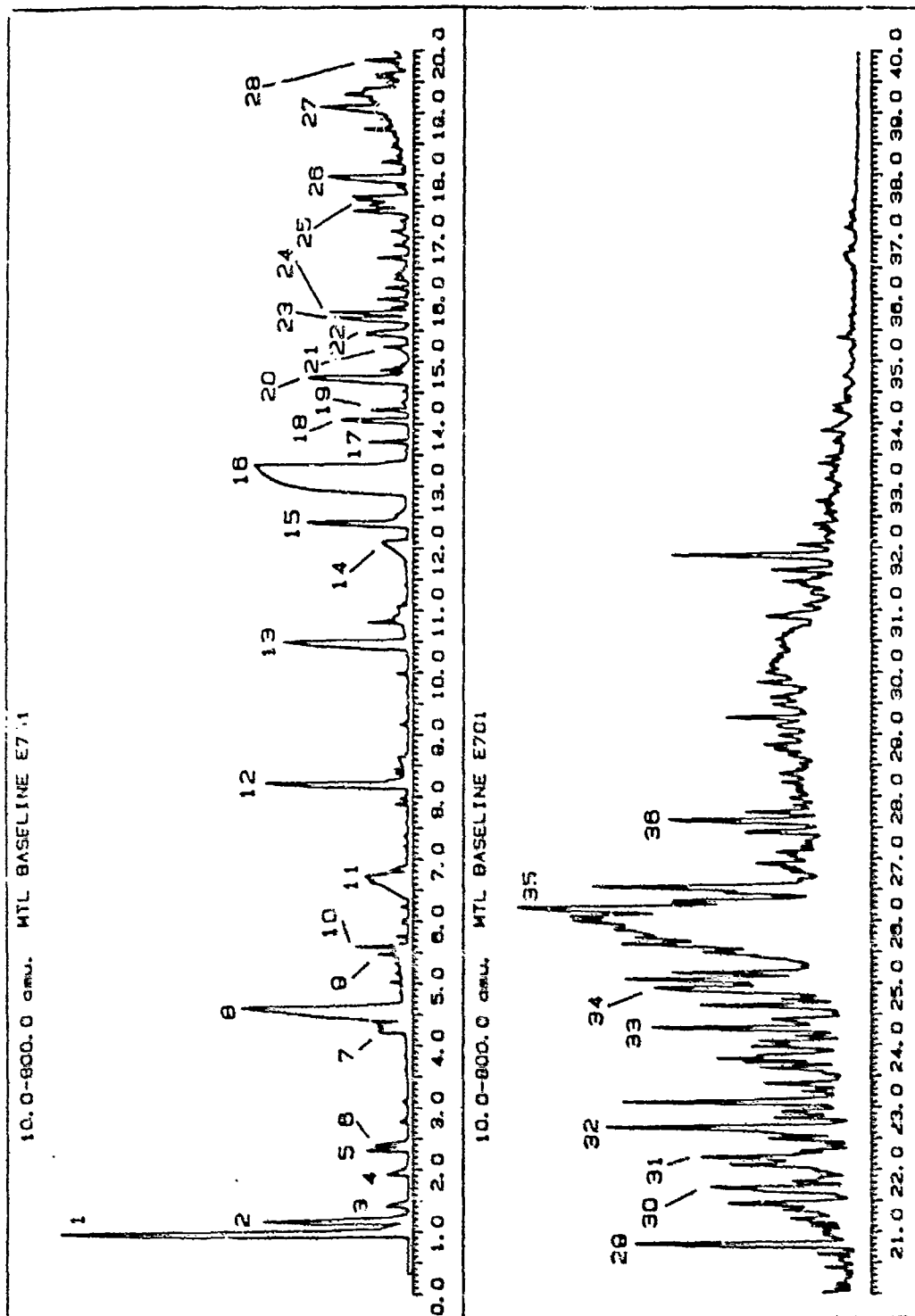
Figure 5 Pyrolysis/gas chromatography/mass spectrometry of MTL-1 E-701 baseline; 900°C in Helium.
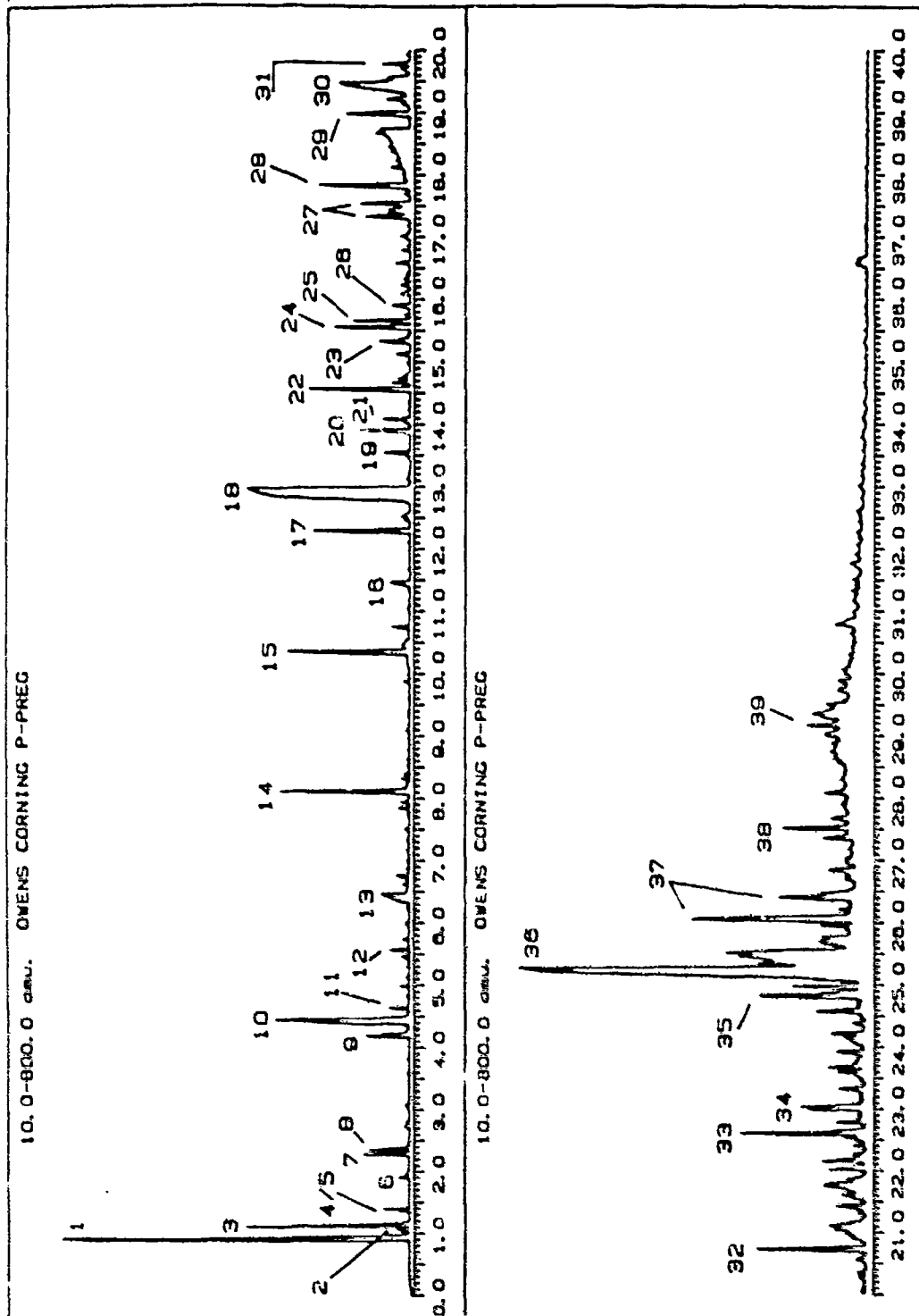
Figure 6 Pyrolysis/gas chromatography/mass spectrometry of VTL-2, Owens-Corning; 900°C in Helium.
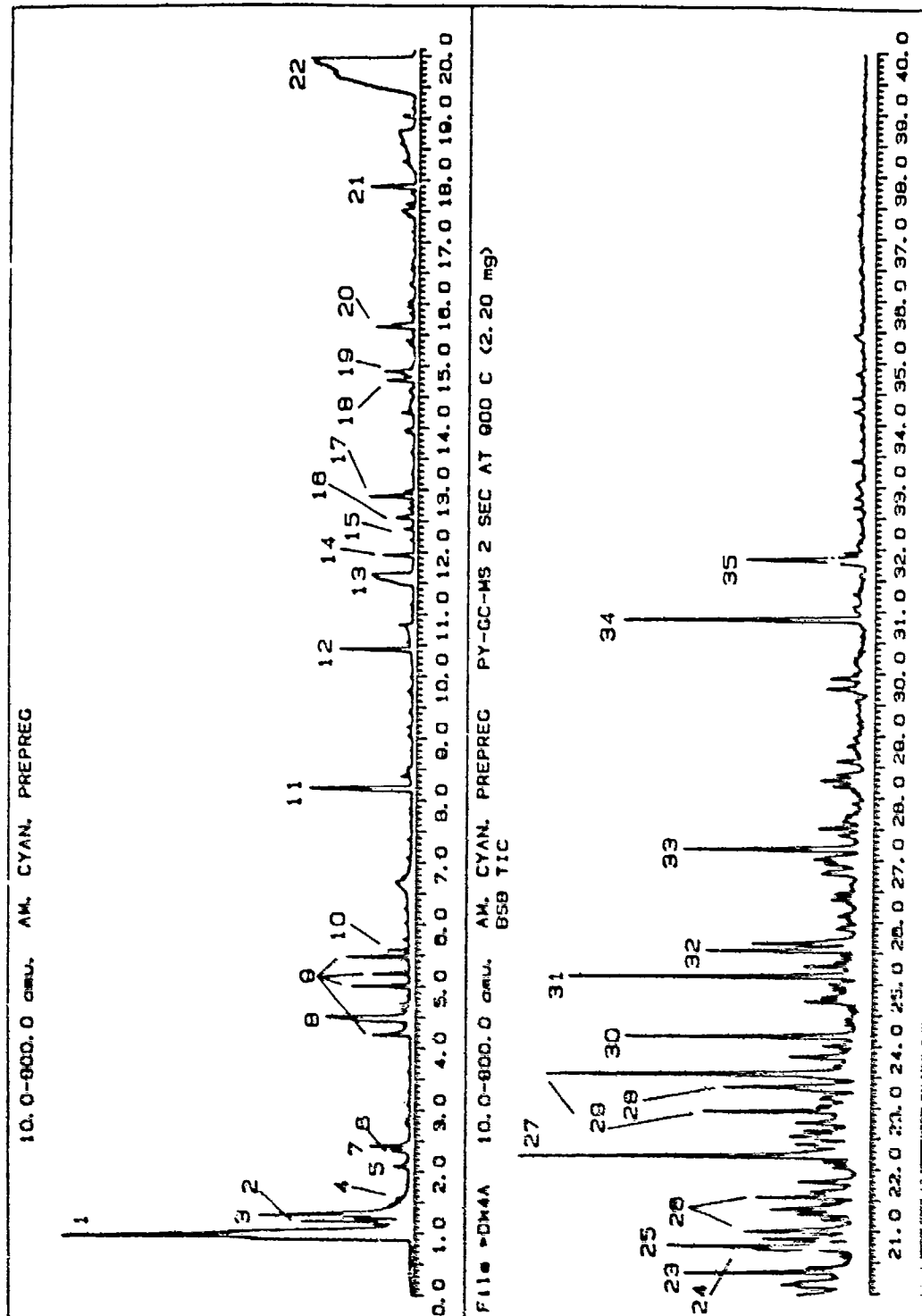
Figure 7 Pyrolysis/gas chromatography/mass spectrometry of MTL-3, American-Cyanamide; 900°C in Helium.
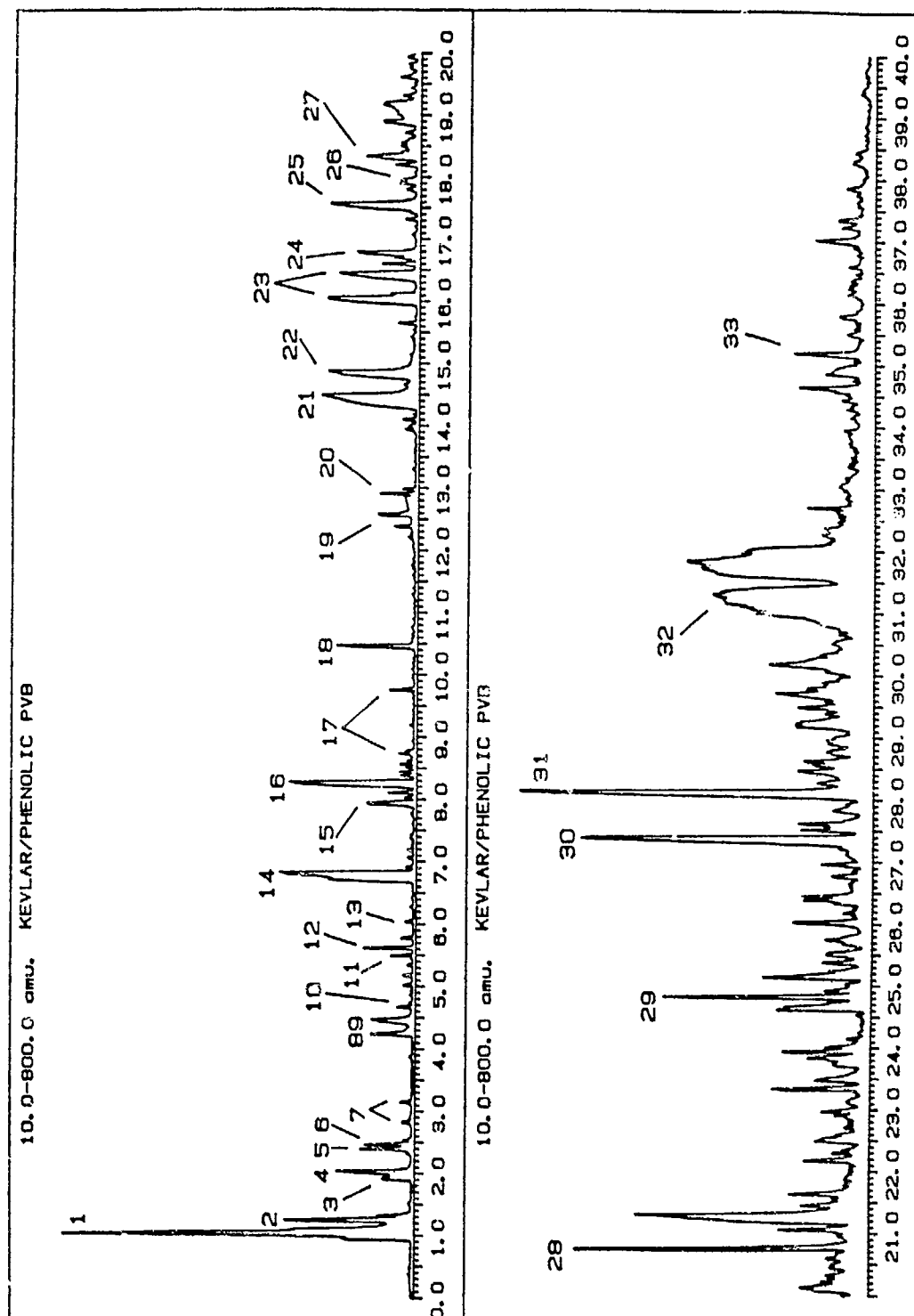
Figure 8. Pyrolysis/gas chromatography/mass spectrometry of MTL-4, Russell Corporation; 900°C in Helium.
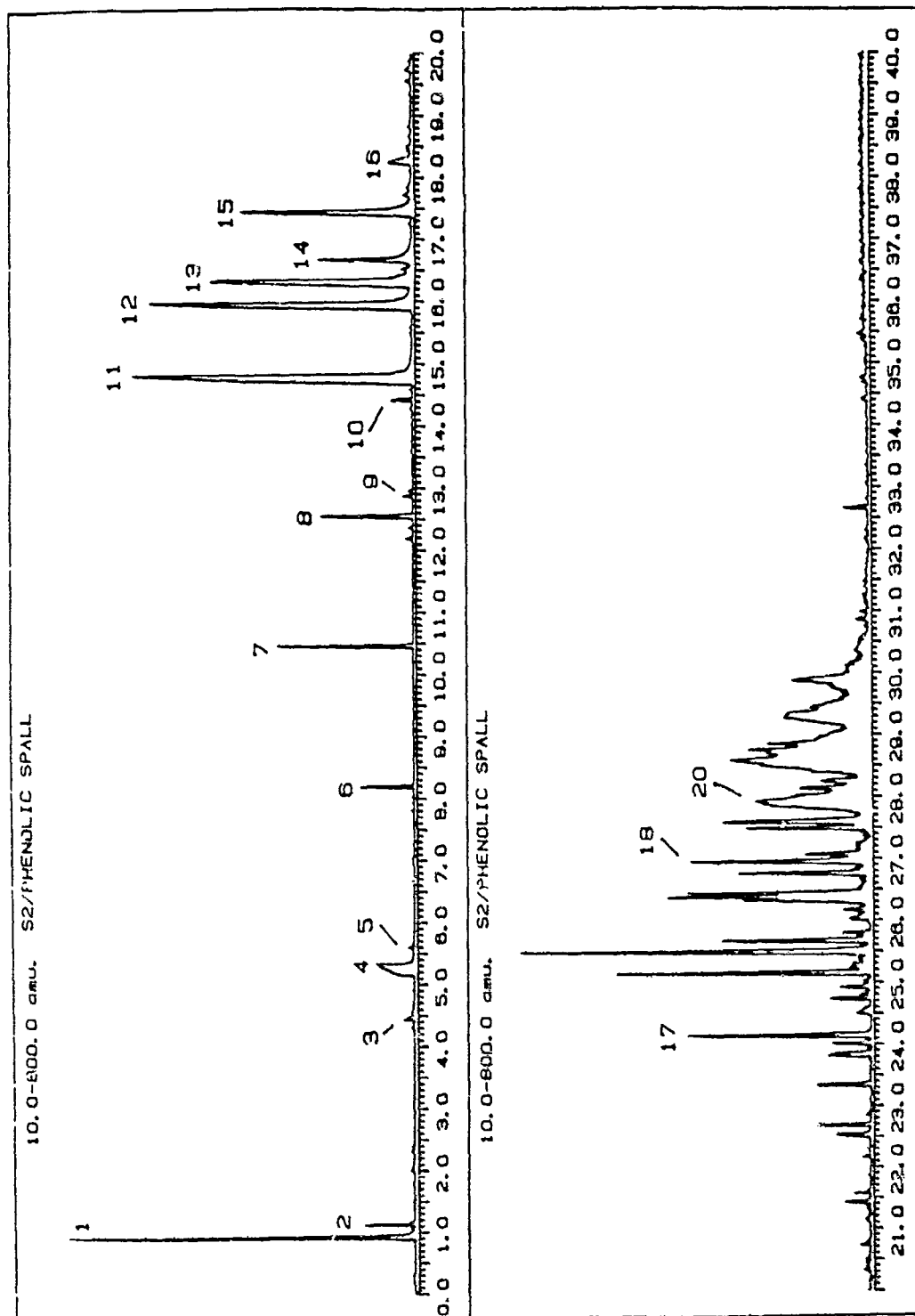
Figure 9 Pyrolysis/gas chromatography/mass spectrometry of MTL-5, Owens-Corning; 900°C in Helium.

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DISCUSSION

The results of the dynamic thermogravimetric analysis experiments, presented in Table 2 and Figure 1, demonstrate that composite samples MTL-1 through MTL-3 sustain little thermal damage below 200°C (392°F). The major mass loss occurs in the region 200°C through 500°C (392°F through 932°F) due to decomposition of the matrix resin. In all three compositions the maximum mass loss rate occurs at 350°C through 400°C (662°F through 752°F). MTL-4 and MTL-5 are of a different composition. In the case of MTL-4, and organic fiber (Kevlar) is combined with an organic matrix resin. The experimental results show little decomposition up to 200°C (392°F), but major decomposition occurs between 200°C and 800°C (392°F through 1472°F). Mass loss maxima occur at 390°C, 580°C, and 600°C (734°F, 1076°F, and 1112°F), respectively. In MTL-5, we find a material that sustains minimal mass loss until the temperature exceeds 300°C (572°F) with the maximum mass loss rate occurring at 525°C (977°F). These data are in good agreement with the estimated ignition temperatures determined at FMRC by Tewarson.[2]

The results of the isothermal decomposition experiments, as presented in Table 3 and Figure 2, indicate the response of the composites when suddenly exposed to temperatures of 200°C through 500°C (572°F through 932°F) and held at that level for five minutes. The results demonstrate that all of the materials evaluated will withstand thermal exposures up to 300°C (572°F) quite successfully.

The results of experimental determinations of oxygen index and the temperature dependence of oxygen index, as shown in Table 4 and Figure 3, demonstrate the degree of difficulty encountered in ignition and sustained combustion for the composite materials evaluated. Keeping in mind the fact that normal atmosphere contains nearly 21% oxygen, any material whose oxygen index is 21% or less can be expected to ignite and sustain combustion under normal atmospheric conditions. Materials whose oxygen index is more than 21%, but less than 26%, will ignite with more or less difficulty and should self-extinguish when the flame source is removed. Materials whose oxygen index is greater than 27% are not expected to ignite under normal conditions. Using these general guidelines, only MTL-1 would be expected to ignite and sustain combustion under normal atmospheric conditions. Samples MTL-2 and MTL-4 might ignite but would most likely extinguish when the flame source was removed. Samples MTL-3 and MTL-5 would be expected to ignite only with considerable difficulty and flame propagation would not be sustained.

The importance of the temperature dependence data is realized when one considers that in a fire the thermal environment of a material will normally elevate due to the combustion of surrounding structures. The behavior of the material under examination, at elevated temperatures, then becomes important. In general, the oxygen requirement for sustained combustion will decrease as the temperature of a material increases; i.e., the oxygen index decreases. When the oxygen index falls to the level of oxygen present, at a given temperature, a flashover will occur and the material will combust. The overall fire load will be increased to the degree that new, combustible material becomes involved.

If we consider the data shown in Table 4 at temperatures between 100°C through 300°C (212°F thro... . 572°F) one can be certain that composites MTL-1 and MTL-2 would easily sustain combustion at 200°C (414°F) and beyond. MTL-4 would have to reach a temperature above 300°C (572°F); MTL-3 and MTL-5 would require temperatures in excess of 300°C (572°F) in order to sustain combustion since their oxygen index values are considerably higher

at that temperature level. The increase in oxygen index of composites MTL-3 and MTL-5 have behavior similar to that noted earlier[3] with other polymers that contain a halogenated molecule which acts as a flame retardant. Such a species has been detected in the resin formulation of MTL-3. Because no such molecular species was detected in the resin formulation of MTL-5, it must be assumed that char formation, or a similar characteristic common to phenolics, is responsible for the high oxygen index values observed with this material. The enhanced fire resistance of the phenolic is supported by its negligible mass loss rate and low fire propagation index as determined by Tewarson.[2]

The smoke generation characteristics of MTL-1 through MTL-5 are presented in Table 5, and a representative data plot is shown in Figure 4. Data for time to Ds = 16 indicates the amount of time available before it would be difficult to locate an escape route on the order of 10 feet away. Time to Ds = 264 indicates the time before a light transmission level is reached where vision is no longer possible. The value of Dm (corr) indicates the maximum optical density obtained corrected for the particulate matter deposited on the windows within the smoke chamber that protect the light source and the photometric detector. Order of magnitude values would be:

- Low Smoke Generation — Dm = <200

- Moderate Smoke Generation — Dm = 200 through 450

- High Smoke Generation — Dm = >450

The exact numerical values may be academic once a value of Dm = 264 is exceeded, however, the maximum smoke density does indicate the relative smoke load produced by each material.

Perhaps a more instructive parameter is the value of smoke density per gram (SD/G) of material consumed because it provides a direct relationship between a quantity of material and the level of smoke generation. Of the two types of material evaluated, MTL-3 and MTL-5 are best choices in their respective classes on the basis of smoke generation.

Attempts to evaluate the toxicity of combustion effluent from burning organic materials has resulted in an ongoing debate within the fire science community. Apart from the fact that the thermal environment of a fire produces a complex set of reaction conditions that may seldom be duplicated in any two successive events, the combustion of organic materials will always produce carbon monoxide and carbon dioxide, in large quantity, in addition to everything else. For these reasons we have elected to take an instrumental approach to evaluating the potential toxicity of combustion effluent generated by organic materials. The experimental results obtained can then be reviewed for the presence of particularly hazardous species.

3. MACAIONE, D. P. *Flammability Characteristics of Some Epoxy Resins and Composites.* U.S. Army Materials Technology Laboratory, MTL TR 83-53, September 1983.

Within this context, the data presented in Tables 6 through 10 and Figures 5 through 9 indicate that the components of the effluent resulting from the combustion of MTL-1 and MTL-2 are quite similar. In the case of MTL-3, although it is a polyester resin producing many chemical species of the same or similar type as MTL-1 and MTL-2 it, in addition, produces hydrogen chloride (HCL) presumably due to the decomposition of chlorendic acid which is present as a flame retardant additive. The composition of MTL-4 differs from the first three materials. Although many of the combustion effluent components detected are common to all five materials, the presence of hydrogen cyanide (HCN) was detected in the effluent from MTL-4. Because some, or all, of the matrix resin in MTL-4 and MTL-5 is phenolic in nature, the combustion effluent from these composites exhibits several phenolic compounds.

CONCLUSIONS

The fire survivability of an Army combat vehicle and crew has been a major concern and obstacle to the general application of structural composites by the military. An understanding of the flammability behavior and overall fire tolerance of organic materials is crucial to the proper selection of materials which must occur in the initial stage of vehicle design.

The study described in this report was undertaken to assess the flammability characteristics of fiber-reinforced composite materials in view of their potential application in combat vehicle systems. Five fiber-reinforced composite compositions were evaluated; three were candidate hull materials and two were spall liner materials. Considering the potential hazards due to fire and the generation of heat and combustion products, the results indicate that these would be limited to the ignition zone.

Based upon the results obtained in this investigation, it has been shown that a military vehicle fabricated from these fiber-reinforced composite materials would not represent an unusual fire hazard by virtue of its construction and that composites such as the ones examined in the current study would, most likely, respond in such a manner as to increase the fire survivability of the system.

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Domenic P. Macaione

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Key Words

Polymers
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Fire resistance

The use of composites in Army systems as a means of decreasing weight and enhancing surviva-
bility, without reducing personnel safety, has been considered for some time. The U.S. Army
Materials Technology Laboratory (MTL) has successfully demonstrated, in an earlier program, that
a ground vehicle turret could be fabricated from fiber-reinforced composite material. That tech-
nology has now been applied to the fabrication of a composite vehicle hull. Organic poly-
mers are one of the major constituents of fiber-reinforced composites. As components of
military systems, these materials are expected to survive combustion and pyrolysis pro-
cesses associated with fires. It is thus necessary to develop an understanding of the flamma-
bility behavior of composite materials in the early design stages of a military vehicle such as
the Composite Infantry Fighting Vehicle (CIFV). The present study attempts to characterize
the flammability behavior of composite materials associated with the CIFV Hull Program in
terms of accepted fire resistance parameters.